



- (51) **International Patent Classification:**
F03D 11/02 (2006.01) *F03D 9/00* (2006.01)
F16H 47/04 (2006.01)
- (21) **International Application Number:**
PCT/EP2009/053302
- (22) **International Filing Date:**
20 March 2009 (20.03.2009)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (71) **Applicant (for all designated States except US):** **AMSC Windtec GmbH** [AT/AT]; Schleppeplatz 5, A-9020 Klagenfurt (AT).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** **FISCHER, Martin** [NL/AT]; Mozartstrasse 86, A-9020 Klagenfurt (AT). **WEICHBOLD, Peter** [AT/AT]; Linsengasse 29, A-9020 Klagenfurt (AT). **TRATNIG, Robert** [AT/AT]; Triebblach 14, A-9173 St. Margareten (AT).
- (74) **Agent:** **BARTH, Stephan**; Friedrichstrasse 31, 80801 München (DE).

- (81) **Designated States (unless otherwise indicated, for every kind of national protection available):** AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States (unless otherwise indicated, for every kind of regional protection available):** ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report (Art. 21(3))
- with amended claims and statement (Art. 19(1))

(54) **Title:** METHOD FOR OPERATING A WIND ENERGY CONVERTER, CONTROL DEVICE FOR A WIND ENERGY CONVERTER, AND WIND ENERGY CONVERTER

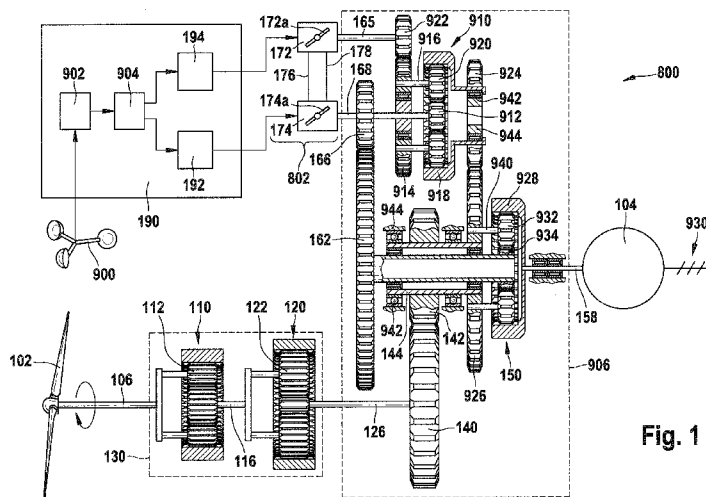


Fig. 1

(57) **Abstract:** Some general aspects of the invention provide a method for operating a wind energy converter having a variable-ratio gear system (906, 172-178) mechanically coupled between a rotor (102) and a generator (104), wherein the variable-ratio gear system (906, 172-178) includes a first transmission unit (174) coupled to a first shaft (168) and a second transmission unit (172) coupled to a second shaft (165). The method comprises adjusting the variable-ratio gear system (906, 172-178) to a first gear ratio at which the first shaft (168) substantially does not rotate; determining a wind speed (300) or a related parameter (n, P, p); detecting whether the wind speed (300) or the related parameter (n, P, p) has crossed a first threshold value (310) in a first direction; and adjusting the variable-ratio gear system (906, 172-178), when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction, to a second gear ratio at which the second shaft (165) substantially does not rotate. Under further aspects, the invention provides a control device (190) for a wind energy converter having a variable-ratio gear system and a wind energy converter comprising the control device (190).

WO 2010/105692 A1

- 1 -

DESCRIPTION

Background

5 Method for operating a wind energy converter, control device for a wind energy converter, and wind energy converter.

The present invention relates to a wind energy converter.

10

Wind energy can be converted into useful forms, such as electricity, by a wind energy converter that includes a rotor, e.g. a low-speed propeller, coupled to a generator.

15 Since the speed of wind at a given location in general fluctuates with changing weather conditions, conventional wind energy converters are typically operated with variable rotor speed in order to achieve a high aerodynamic efficiency of the rotor at different levels of wind speed.

20 In some implementations, to supply electricity into an electric power grid, it is advantageous to use a constant-speed generator such as a synchronous generator directly connected to the grid for power transmission. In addition to economic benefits, the quality of the electric power fed
25 into the grid is usually higher without a power converter, which can be expensive. Furthermore, the constant speed generator can be operated at a medium voltage level such that no additional transformer is needed.

- 2 -

DE 10 2005 054 539 B3 discloses one example of a wind energy converter including a rotor and an electrical generator for direct connection to an electric power grid. In this example, the rotor and the generator are coupled by a variable-ratio gear system that includes a hydraulic component for controlling the gear ratio of the variable-ratio gear system. As a result, the wind energy converter operates at a variable rotor speed according to the speed of wind while driving the generator at a constant speed.

10

In the above example, while aerodynamic losses of the wind energy converter can be reduced by adjusting the rotor speed to changes in the speed of wind, a substantial portion of the power is transported from the rotor to the generator via the hydraulic component of the variable-ratio gear system. As hydraulic components generally suffer power losses by leakage flow, friction losses etc., the overall efficiency of the wind energy converter is reduced due to the power losses in the hydraulic component of the variable-ratio gear system.

15
20

Summary

25 One general aspect of the invention relates to a method for operating a wind energy converter that has a variable-ratio gear system mechanically coupled between a rotor and a generator, wherein the variable-ratio gear system includes a first transmission unit, e.g. a hydraulic unit, 30 coupled to a first shaft, and a second transmission unit,

- 3 -

e.g. a hydraulic unit, coupled to a second shaft. The method includes adjusting the variable-ratio gear to a first gear ratio at which the first shaft substantially does not rotate. For example, the first shaft does not rotate at all or rotates at a rotational speed that is negligibly low compared to a range of rotational speeds at which the first shaft rotates when the gear ratio of the variable-ratio gear system is varied over a range of gear ratios, assuming a constant generator speed.

10

Embodiments of this method may include one or more of the following features.

A wind speed is determined. For example, a wind-speed value that characterises a current wind speed is determined directly from wind measurement or indirectly from operating parameters of the wind energy converter. Further, the method also includes detecting whether the wind speed has crossed a first threshold value in a first direction. For example, the first direction may be predefined as the direction corresponding to a rise in wind speed, such that a detection that the wind speed has crossed the first threshold value occurs when the wind speed has risen beyond, i.e. has become greater than the first threshold value. Alternatively, the first direction may be predefined as the direction corresponding to a decrease in wind speed, such that a detection that the wind speed has crossed the first threshold value occurs when the wind speed has fallen below, i.e. has become less than the first threshold value.

- 4 -

In some embodiments, when it is determined that the wind speed has crossed the first threshold value in the first direction, the variable-ratio gear system is adjusted to a
5 second gear ratio at which the second shaft substantially does not rotate,. In this event the rotational speed of the second shaft is equal to zero, for example, or is negligibly low when compared to a range of rotational speeds at which the second shaft rotates when the gear
10 ratio of the variable-ratio gear system is varied over the range of gear ratios of the variable-ratio gear, assuming a constant generator speed.

Using the above method, the gear ratio of the variable-
15 ratio gear system is changed from a first gear ratio at which the first shaft coupled to the first hydraulic unit substantially does not rotate to a second gear ratio at which the second shaft coupled to the second hydraulic unit substantially does not rotate. In this way, gear ratios at
20 which both the first and the second shaft are in substantial rotation are avoided, thus reducing energy loss in the hydraulic units, which typically is greater for higher rotational speeds of the shafts coupled to the hydraulic units. Therefore, the method enables to operate a
25 wind energy converter having a variable-ratio gear system that includes a hydraulic component in such a way that the energy loss in the hydraulic units and thereby in the variable-ratio gear system as a whole is significantly reduced while the rotor is still able to operate at

- 5 -

different rotor speeds in accordance with varying wind conditions.

5 The method can further include driving the generator at a constant generator speed. This allows a synchronous generator to be directly connected to a power grid, without necessarily requiring the use of a power converter that can be both expensive and energy inefficient. In some
10 embodiments, at least one of the first gear ratio and the second gear ratio corresponds to one of a minimum operational speed and a nominal maximum speed of the rotor, when the generator is driven at the constant generator speed. In this way, the lower and/or upper limits of the
15 operational range of physically possible rotor speeds of the wind energy converter can be utilised, thus enabling high efficiency over a particularly wide range of wind speeds by utilising the physical capabilities of the rotor to the respective limit(s).

20 In some embodiments, the method further includes uncoupling the first shaft from the first hydraulic unit, when the wind speed has crossed the first threshold value in the first direction. In this situation, as the second shaft,
25 which is coupled to the second hydraulic unit, substantially does not rotate, substantially no power is transmitted hydraulically or mechanically between the first and second hydraulic units. By uncoupling the first shaft from the first hydraulic unit, further power transmission

- 6 -

between the first shaft and the first hydraulic unit is disabled, enabling the first hydraulic unit to decelerate to zero speed e.g. by its own friction. In this way, both the first and second hydraulic units are configured to
5 operate at zero speed, thus further reducing hydraulic losses in the variable-ratio gear system and achieving a particularly high efficiency of the wind energy converter.

In some embodiments, the method further includes braking
10 the first hydraulic unit when the wind speed has crossed the first threshold value in the first direction. This can advantageously increase the operational stability of the wind energy converter in this operational state and can further ease the load on the first hydraulic unit for
15 increasing the life span of the hydraulic unit.

In some embodiments, when the wind speed has crossed the first threshold value in the first direction, a swivel angle of the first hydraulic unit is adjusted so that a
20 hydraulic flow through the first hydraulic unit is substantially stopped. This effectively stops hydraulic power flow between the first and second hydraulic units, such that the braking of the first hydraulic unit enables to indirectly brake the second hydraulic unit, too, or to
25 dampen the second hydraulic unit, depending on a swivel angle setting of the second hydraulic unit. This can improve the operational stability of the wind energy converter in this operational state.

- 7 -

In some embodiments, the first and second hydraulic units are connected by at least one hydraulic conduit. The method further includes blocking at least one hydraulic conduit when the wind speed has crossed the first threshold value
5 in the first direction. This also stops hydraulic power flow between the first and second hydraulic units, and indirectly brakes or dampens the second hydraulic unit for improving the operational stability of the wind energy converter in this operational state. Furthermore, the
10 hydraulic load on the first hydraulic unit is eased, resulting in an increase in the hydraulic unit's life span.

In some embodiments, at least one hydraulic conduit is interconnected by a bypass, and the method further includes
15 regulating the bypass when the wind speed has crossed the first threshold value in the first direction. For example, the bypass may be initially closed and then be opened when the wind speed has crossed the first threshold value in the first direction. This enables to control the damping of the
20 second hydraulic unit while reducing hydraulic load on the first hydraulic unit for increasing its life span.

In some embodiments, the method further includes detecting whether the wind speed has crossed a second threshold value
25 opposite to the first direction, and if so, adjusting the variable-ratio gear system to the first gear ratio. In this way, gear ratios other than the first and second gear ratio are avoided for both cases of rising and falling wind

- 8 -

speed, thereby reducing power losses for achieving a particularly high overall efficiency.

In some embodiments, the second shaft is uncoupled from the second hydraulic unit when the wind speed has crossed the
5 second threshold value inversely to the first direction for achieving benefits analogous to those achieved by the uncoupling of the first hydraulic unit. Similarly, the second hydraulic unit is braked when the wind speed has
10 crossed the second threshold value inversely to the first direction for achieving benefits analogous to those achieved by the braking of the first hydraulic unit. Another general aspect of the invention provides a system and a method for improving the energy efficiency of a wind
15 energy converter having a first and a second active module. The system includes a sensor system for obtaining a measurement of a wind condition (for example, a local wind speed). A controller is coupled to the sensor system for determining, according to the obtained measurement, whether
20 a pre-determined operational condition is satisfied. Based on a result of the determination, the controller generates a signal for adjusting a configuration of a selected one of the first and the second active module to achieve a predetermined power characteristic of the wind energy
25 converter.

Embodiments of this aspect may include one or more of the following features.

- 9 -

Using the obtained measurement, the controller determines whether a first or a second operational condition is satisfied and according to the result, generates a signal for adjust the configuration of a corresponding one of the
5 first and second active modules.

For example, when a magnitude of the obtained measurement has crossed a first threshold value in a first direction, the controller determines that the first operational
10 condition is satisfied and subsequently generates a signal for adjusting the configuration of the first active module. Similarly, when the magnitude of the obtained measurement has crossed a second threshold value in a second direction opposite to the first direction, the controller determines
15 that the second operational condition is satisfied and subsequently generates a signal for adjusting the configuration of the second active module.

20 The systems and methods described herein provide significant advantages over the known prior art. By operating the variable-ratio gear system in such a way that at least one of the transmission units, e.g. hydraulic units, is at or close to zero speed, the transmission of
25 power through the hydraulic units can be significantly reduced. The above-mentioned advantages can also help to increase the efficiency of energy conversion of the wind energy converter, to reduce noise emissions from the hydraulic units, and furthermore to reduce cost including

- 10 -

maintenance cost by increasing the lifespan of the hydraulic units.

Other features and advantages are illustrated in the accompanying drawings and described in detail in the
5 following part of the description.

Figures

10 In the Figures:

Fig. 1 is a schematic illustration of a wind energy converter according to an embodiment of the invention, the wind energy converter having
15 a variable-ratio gear system including a first hydraulic unit coupled to a first shaft and a second hydraulic unit coupled to a second shaft;

20 Fig. 2A is a schematic diagram showing, for the wind energy converter of FIG. 1, a rotational speed of a first shaft, a rotational speed of a second shaft, and an amount of power transferred between the hydraulic units as
25 functions of the rotor speed;

Fig. 2B is a schematic diagram showing, for the wind energy converter of Fig. 2A, a hydraulic

- 11 -

power loss in the hydraulic units as a function of the rotor speed;

Fig. 3 is a schematic diagram showing, for a wind energy converter operated according to a method of an embodiment, a dependency of the rotor speed on the speed of wind; and

Fig. 4 is a schematic illustration of a wind energy converter according to a further embodiment.

Throughout the figures the same reference numbers indicate the same or functionally equivalent means.

15 Detailed Description

Figure 1 is a schematic illustration of a wind energy converter 800, which includes a control device 190 configured for improving the energy efficiency of wind energy converter 800. Prior to describing the control device 190 in detail, the following section first discusses the structure and the operation of the wind energy converter 800.

25 As shown in Fig. 1, the wind energy converter 800 includes a rotor 102 (e.g. a low speed propeller) that drives a generator 104 (preferably a constant speed synchronous generator) through a gear train 130, 906, 802. The gear train 130, 906, 802 includes a constant-ratio gear box 130 and a variable-ratio gear system 906, 802 the gear ratio of

30

- 12 -

which is controllable by the control device 190. In this description, the gear ratio of the variable-ratio gear system 906, 802 corresponds to, or is defined in association with, the ratio between the rotational speeds at the input terminal (shaft 126) and the output terminal (shaft 158) of the variable-ratio gear system 906, 802.

The rotor 102 is connected to the constant-ratio gearbox 130 through a rotor shaft 106. The constant-ratio gearbox 130 is configured to transfer power from the low speed, high torque rotor shaft 106 to a high speed, low torque interconnecting shaft 126. Purely as an example, the constant ratio gearbox 130 is shown to include a first epicyclic gearing 110 and a second epicyclic gearing 120. Power from the rotor shaft 106 is transmitted, e.g., first to a planet carrier 112 of the first epicyclic gearing 110, and then via a shaft 116 to the planet carrier 122 of the second epicyclic gearing 120. Both epicyclic gearings 110 and 120 are configured to give constant step-up ratios so that the speed of rotation gradually increases from the rotor shaft 106 at the input of the constant ratio gearbox 130 to the interconnecting shaft 126 at the output of the constant ratio gearbox 130. In other embodiments, the constant ratio gearbox 130 may include additional or fewer gears configured in a different way to transmit power from the rotor shaft 106 to the interconnecting shaft 126.

The interconnecting shaft 126 connects the torque output of the constant ratio gearbox 130 to a torque input of the

- 13 -

variable-ratio gear system 906, 802. The variable-ratio gear system 906, 802 functions as a superposition gear having a mechanical component 906 and a hydraulic component 802. The mechanical component 906 includes a spur gear 140
5 driven by the interconnecting shaft 126. The spur gear 140 meshes with a pinion 142 and transmits power via a shaft 144 to a third epicyclic gearing 150. The shaft 144 is rotatably held by a bearing 942 resting on a rigid support 944, which is e.g. attached to a housing (not shown) of the
10 wind energy converter 800, such as a nacelle rotatably disposed on a tower.

The third epicyclic gearing 150 driven by the shaft 144 has three basic components: a planet carrier 940 carrying a set
15 of planet gears 932, an annulus 928, and a sun gear 934. The planet carrier 940 receives input from the shaft 144 and thus rotates at a speed proportional to the speed of the rotor 102. The annulus 928 of the third epicyclic gearing 150 is coupled to the generator 104 via an output
20 shaft 158 of the variable ratio gear system 906, 802, and rotates at the same speed as the generator 104.

The sun gear 934 of the third epicyclic gearing 150 is connected to a sun gear 912 of a fourth epicyclic gearing
25 910 via a spur gear 162 and a pinion 166. In addition to the sun gear 912, the fourth epicyclic gearing 910 includes a planet carrier 916 carrying planet gears 920 and an annulus 918 as basic components. The annulus 918 of the fourth epicyclic gearing 910 is connected to the shaft 144

- 14 -

and thus also to the planet carrier 940 of the third epicyclic gearing 150 via a further pinion 924 meshing with a further spur gear 926. Thus, the annulus 918 rotates at a speed proportional to the speed of the rotor 102.

5

The sun gear 912 of the fourth epicyclic gearing 910 is furthermore connected to a first shaft 168 coupled to a first hydraulic unit 174 of the hydraulic component 802 of the variable ratio gear system 906, 802. The hydraulic
10 component 802 furthermore includes a second hydraulic unit 172 and hydraulic conduits 176, 178 interconnecting the first 174 and second 172 hydraulic units, thereby forming a hydraulic circuit 174, 176, 172, 178 in which power is transferrable between the hydraulic units 174, 172 by a
15 circulating hydraulic fluid. The second hydraulic unit 172 is coupled to a second shaft 165, which is connected via a pinion 922 and a spur gear 914 to the planet carrier 916 of the fourth epicyclic gearing 910. Both hydraulic units 174, 172 have a respective swash plate 174a, 172a with a
20 respective controllable swivel angle. For example, the hydraulic units 174, 172 are hydraulic motors or pumps such as axial piston pumps. Each hydraulic unit performs a conversion between the rotational motion of a respective one of the first 168 and second 165 shafts and the
25 hydraulic flow through the hydraulic circuit 174, 176, 172, 178.

The setting of the swivel angle of the swash plate 174a of the first hydraulic unit 174 sets the relationship between

- 15 -

an amount Q of the hydraulic fluid flowing through a cross section of the hydraulic circuit 174, 176, 172, 178 (e.g., a cross section of one of the hydraulic conduits 176, 178) during a given time span and an angular distance θ_1 through
5 which the first shaft 168 rotates during the same time span. Similarly, the swivel angle of the swash plate 172a of the second hydraulic unit 172 sets the relationship between the amount Q of hydraulic fluid flowing through a cross section of the hydraulic circuit 174, 176, 172, 178
10 and an angular distance θ_2 through which the second shaft 165 rotates during a corresponding time span. Therefore, the hydraulic component 802 of the variable-ratio gear system 906, 802 functions as an infinitely variable gear system in which torque (and thus power) is transmitted
15 between the first 168 and second 165 shafts. The direction and amount of the power transmitted between the shafts can be controlled by the setting of the swivel angles of the swash plates 174a, 172a.

20 The variable-ratio gear system 906, 802 as shown in Fig. 1 functions as a superposition gear system in which two additional torque paths are superimposed upon a main torque path that connects the output of the constant ratio gearbox 130 to the input of the generator 104. The main torque path
25 includes the interconnecting shaft 126, the spur gear 140, the pinion 142, and the planet gears 932 and annulus 928 of the third epicyclic gearing 150.

- 16 -

The first superimposed torque path branches off the main torque path at the shaft 144 and leads through the spur gear 926, the pinion 924, the fourth epicyclic gearing 910, the pinion 166, the spur gear 162 and the sun gear 934 of the third epicyclic gearing 150 before rejoining the main torque path at the planet gears 932 of the third epicyclic gearing 150.

The second superimposed torque path branches off the first superimposed torque path at the planet gears 920 of the fourth epicyclic gearing 910 and leads through the spur gear 914, the pinion 922, and the second shaft 165 coupled to the second hydraulic unit 172 where the torque on the second shaft 165 is converted into a hydraulic flow through the hydraulic conduits 176, 178. After the hydraulic flow is re-converted by the first hydraulic unit 174 into a torque on the first shaft 168, the second superimposed torque path continues through the first shaft 168 to the pinion 166 where it rejoins the first superimposed torque path.

In the example of FIG. 1, the variable-ratio gear system 906, 802 functions as a superposition gear system having at least two superimposed torque paths in addition to a main torque path, wherein one of the superimposed torque paths includes a hydraulic circuit having at least a first and a second hydraulic unit hydraulically interconnected.

- 17 -

FIGS. 2A and 2B illustrate the operation of this variable-ratio gear system 906, 802 in detail, assuming that the generator 104 is driven at a substantially constant speed by the output of the variable-ratio gear system 906, 802.

5

In Fig. 2A, a horizontal axis represents the rotational speed 200 of the rotor 102 of the wind energy converter. Based on the assumption of constant generator speed, the rotor speed 200 is directly - proportionally or inversely, according to definition - related to the gear ratio of the variable-ratio gear system 906, 802, which is controllable via the settings of the hydraulic units 172 and 174, e.g. the combined settings of the swivel angles of the hydraulic units.

15

In this figure, three variables are shown as functions of the rotor speed 200, each in arbitrary units along a common vertical axis 202. The three variables include a rotational speed 214 of the first hydraulic unit 174, a rotational speed 212 of the second hydraulic unit 172, and an amount of power 216 transferred hydraulically between the two hydraulic units. For each hydraulic unit, the respective rotational speed 212, 214 shows a near linear relationship to the rotor speed 200.

25

The rotational speed 214 of the first hydraulic unit crosses the horizontal axis 200, i.e. changes its rotational direction, at an upper zero point 208 of the variable-ratio gear system. Likewise, the rotational speed

- 18 -

212 of the second hydraulic unit crosses the horizontal axis 200, i.e. changes its rotational direction, at a lower zero point 206 of the superposition gear system. Here, the respective correspondence of the first and second hydraulic unit to the upper 208 and lower 206 zero points has been
5 chosen arbitrarily purely for illustrative reasons. The power 216 transferred between the hydraulic units reverses direction at both the lower 206 and upper 208 zero points, and it exhibits a local minimum 218 in terms of its
10 absolute amount approximately midway between the lower 206 and upper 208 zero points.

Fig. 2B shows the amount of hydraulic power loss 205 as a function of rotor speed for the variable-ratio gear system
15 906, 802 of FIG. 1 operating in the same range of rotor speed 200 as in FIG. 2A. The hydraulic power loss 205 is seen to exhibit a respective local minimum at each of the lower 206 and upper 208 zero points. Due to leakage flow etc. in the hydraulic units, the power loss is still
20 greater than zero at the zero points 206, 208.

Fig. 3 illustrates a method of operating a wind energy converter of the aforementioned kind under conditions of changing wind speed. Above a horizontal axis representing
25 the wind speed 300, which is assumed to fluctuate arbitrarily, solid curves 302, 304 represent the way by which the rotational speed of the rotor 200 is adjusted according to the wind speed 300. Herein, the first solid curve 304 applies to a situation where the wind speed 300

- 19 -

rises, whereas the second solid curve 302 applies to a situation where the wind speed 300 falls.

In this example, when the wind speed 300 is below a first
5 threshold value 310, the rotor speed 200 (as shown by both
curves 302, 304) is fixed at a lower rotor speed limit 322
that corresponds to the lower zero point 206 as shown in
Figs. 2A-B. Preferably, the lower rotor speed limit 322
also corresponds to a minimum operational speed at which
10 the wind energy converter is capable of producing
electricity. When the wind speed 300 is above a second
threshold value 311, the rotor speed 200 (as shown by both
curves 302, 304) is fixed at an upper rotor speed limit 320
that corresponds to the upper zero point 208 as shown in
15 Figs. 2A-B. Preferably, the upper rotor speed limit 320
also corresponds to a maximum operational speed at which
the wind energy converter is capable of producing
electricity, such as a nominal operation speed at which the
rotor can safely operate.

20

If the wind speed 300 starts at a level above the first
threshold value 310 and then falls below it, the gear ratio
of the variable-ratio gear system 906, 802 is adjusted such
that the rotor speed 200 falls to the lower rotor speed
25 limit 322, as shown by the second solid curve 302. If the
wind speed 300 starts at a level below the second threshold
value 311 and then rises beyond it, the gear ratio of the
variable-ratio gear system is adjusted such that the rotor

- 20 -

speed 200 rises to the upper rotor speed limit 320, as shown by the first solid curve 304.

In this example, the gear ratio is adjusted only when the
5 wind speed 300 crosses the threshold values 310, 311,
causing the rotor speed 200 to change, for example, from
the lower rotor speed limit 322 to the upper rotor speed
limit 320, or in the reverse direction. Note that the upper
rotor speed limit 320 and lower rotor speed limit 322
10 respectively correspond to the zero points 206, 208 of the
variable-ratio gear system as shown in Figs. 2A-B, and the
variable-ratio gear system passes gear ratios corresponding
to the region of the local maximum 210 of the hydraulic
losses only transitionally. Thus, the hydraulic losses
15 averaged over a given time interval of operation, such as
one day, are lower than e.g. in an alternative method of
operation illustrated by a dashed line 306, where within a
predefined wind speed interval 314, 316 the rotor speed 200
is continuously regulated according to the wind speed 300
20 to minimize aerodynamic losses of the rotor. Using typical
rotors and hydraulic units, the reduction in hydraulic
power losses according to the method of the solid curves
302, 304 generally outweighs the increase in aerodynamic
power losses compared e.g. to the method of operation
25 illustrated by the dashed line 306.

Together, the threshold values 310, 311 enclose a
hysteresis region 308 that ensures that the frequency at
which the rotor speed (and therefore the gear ratio) is

- 21 -

adjusted between the upper 320 and lower 322 rotor speed limits is kept low. In other embodiments, the first 310 and second 311 threshold values are configured to be equal.

5 Referring now back to FIG. 1, in order to control the speed of the rotor 102, for example, according to the method described above with reference to Fig. 3, the wind energy converter 800 further includes a control device 190 for controlling the swivel angles of the swash plates 174a,
10 172a of the first 174 and second 172 hydraulic units. The control device 190 includes a sensor system 902 that obtains measurements of a local wind condition. In some examples, the sensor system 902 may include a wind speed determiner, which continuously determines the current wind
15 speed by means of a measuring signal received from an anemometer 900. Furthermore, the control device 190 includes a threshold detector 904, which monitors the wind speed obtained from the wind speed determiner 902 and detects when the wind speed rises above and/or falls below
20 a predefined threshold value. Different threshold values may be predefined for falling and rising wind speed in alternative embodiments. In some other examples, the sensor system 902 may additionally or alternatively measure parameters characterizing the operational state of the wind
25 energy converter 800, such as rotor speed n , power P , and hydraulic pressure p . These parameters may also be used by the control device 190 for adjusting the gear ratio of the variable-ratio gear system 906, 802.

- 22 -

In this example, the control device 190 includes a first control unit 192 connected to the threshold detector 904. When the wind speed has risen beyond the threshold value, the first control unit 192 adjusts the variable-ratio gear system 906, 802 to a first gear ratio at which the first shaft 168 substantially does not rotate. The control device 190 further includes a second control unit 194 likewise connected to the threshold detector 904. When the wind speed has fallen beyond the threshold value, the second control unit 194 adjusts the variable-ratio gear system 906, 802 to a second gear ratio at which the second shaft 165 substantially does not rotate.

Fig. 4 is a schematic illustration of a wind energy converter 800 according to a further embodiment. Compared with the wind energy converter of Fig. 1, in this example, a clutch 400 is disposed between the first hydraulic unit 174 and the first shaft 168, which connects - in an operational condition where the clutch 400 is closed - the first hydraulic unit 174 to the mechanical component 906 of the variable-ratio gear system 906, 802. The clutch 400 is connected to the first control unit 192, which is configured to uncouple the first shaft 168 from the first hydraulic unit 174 when the threshold detector 904 has detected that the wind speed has fallen below the threshold value.

The wind energy converter 800 further includes a brake 404 for braking the first hydraulic unit 174. The brake 404 is

- 23 -

connected to the first control unit 192, which is configured to brake the first hydraulic unit 174 together with uncoupling the first shaft 168 from the first hydraulic unit 174. In alternative embodiments, the clutch 400 and the brake 404 may be combined in the form of a double clutch switchable between a first clutch position in which the first hydraulic unit 174 is coupled to the first shaft 168, and a second clutch position in which the first hydraulic unit is coupled to a rigid support such as a housing of the variable-ratio gear system 906, 802, thereby effectively braking the first hydraulic unit 174.

A security brake 402 is provided for braking the first shaft 168 in the event of any of the hydraulic units 174, 172 becoming inoperative, e.g. when hydraulic fluid is lost in the event of a break of one of the hydraulic conduits 176, 178. In alternative embodiments, the brake 404 is configured to be activated by a security brake activator (not shown) in the event of any hydraulic unit 174, 174 becoming inoperative, such that a separate security brake 402 is not needed. In some implementations, the activation of the security brake 402 is always performed in combination with the opening of a hydraulic bypass 406 between the hydraulic conduits 176 and 178.

25

The wind energy converter 800 further includes a faceplate 408 or valve for at least partially blocking the one of the hydraulic conduits 176, 178, e.g. when the hydraulic conduit 176 conducting the hydraulic fluid is under high

- 24 -

pressure. The brake 404 is connected to the first control unit 192, which is configured to shut the faceplate 408 together with brake 404 braking the first hydraulic unit 174 and the first shaft 168 being uncoupled from the first hydraulic unit 174. Furthermore, the wind energy converter 800 includes a bypass 406 that interconnects at least one hydraulic conduit on the side of the second hydraulic unit relative to the faceplate 408. The bypass 406 is connected to the first control unit 192, which is configured to open the bypass 406 at least partially together with shutting the faceplate 408.

The first control unit 192 may further be configured to regulate the bypass 406 for dampening torque variations such that the gear ratio of the variable-ratio gear system 906, 802 is allowed to dynamically vary within a limited interval around the respective zero point, such as the interval 220 shown in Figs. 2A-B, which includes the upper zero point 208 and has a width that is small compared to the distance between the lower 206 and the upper 208 zero point. For example, the rotor 102 may in this way be operated at a nearly fixed speed close the lower zero point 206 of the variable-ratio gear system 906, 802, while allowing the gear ratio to be regulated in a confined gear-ratio interval 220 close to the upper zero point 208, in order to protect the rotor by dampening torque variations at the rotor close to its nominal maximum speed.

- 25 -

Although the present invention has been described with reference to embodiments, it is not limited thereto, but can be modified in various manners which are obvious for a person skilled in the art.

5

In particular, the respective association of the first and second hydraulic units with the lower and upper zero points, and with features such as gear-ratio intervals, clutches, brakes, bypasses etc. in the above description may be reversed, or such features be provided in association with both hydraulic units.

10

The general techniques described above can be applied to a variety of variable rotor speed/constant generator speed drive trains with a variable ratio gear system controlled by an infinitely variable gear, in particular by a hydrostatic circuit consisting of two hydraulic units connected by two pressure lines. The general techniques can also be applied to an infinitely variable gear system controlled by a hydrodynamic circuit (e.g., a VOITH system). Other embodiments are within the scope of the following claims.

20

CLAIMS

1. A method for operating a wind energy converter having a variable-ratio gear system (906, 802) mechanically coupled
5 between a rotor (102) and a generator (104), the variable-ratio gear system (906, 802) including a first transmission unit (174) coupled to a first shaft (168) and a second transmission unit (172) coupled to a second shaft (165), the method comprising:

10

adjusting the variable-ratio gear system (906, 802) to a first gear ratio at which the first shaft (168) substantially does not rotate;

15 determining a wind speed (300) or a related parameter (n , P , p);

detecting whether the wind speed (300) or the related parameter (n , P , p) has crossed a first threshold value
20 (310) in a first direction; and

adjusting the variable-ratio gear system (906, 802), when the wind speed (300) has crossed the first threshold value (310) in the first direction, to a second gear ratio at
25 which the second shaft (165) substantially does not rotate.

2. The method of claim 1, wherein the first and second transmission units (174, 172) are a first and a second

hydraulic unit.

3. The method of claim 1 or 2, further comprising driving the generator (104) at a constant generator speed.

5

4. The method of claim 2, wherein at least one of the first gear ratio and the second gear ratio corresponds to one of a minimum operational speed and a nominal maximum speed of the rotor (102).

10

5. The method of claim 2, further comprising uncoupling the first shaft (168) from the first hydraulic unit (174), when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first

15

direction.

6. The method of claim 5, further comprising braking the first hydraulic unit (174) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

20

7. The method of claim 6, wherein a swivel angle (174a) of the first hydraulic unit (174) is adjusted to substantially stop a hydraulic flow through the first hydraulic unit (174).

25

8. The method of one of claims 5 to 7, the first (174) and second (172) hydraulic unit being connected by at least one hydraulic conduit (176, 178), the method further comprising

- 28 -

blocking the at least one hydraulic conduit (176, 178) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

5

9. The method of one of claims 5 to 8, the at least one hydraulic conduit (176, 178) being interconnected by a bypass (406), the method further comprising regulating the bypass (406) when the wind speed (300) or the related
10 parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

10. The method of claim 2, further comprising:

15 detecting whether the wind speed (300) or the related parameter (n, P, p) has crossed a second threshold value (311) inversely to the first direction; and

adjusting the variable-ratio gear system (906, 802), when
20 the wind speed (300) or the related parameter (n, P, p) has crossed the second threshold value (311) inversely to the first direction, to the first gear ratio.

11. The method of claim 10, further comprising uncoupling
25 the second shaft (165) from the second hydraulic unit (172), when the wind speed (300) or the related parameter (n, P, p) has crossed the second threshold value (311) inversely to the first direction.

- 29 -

12. The method of claim 11, further comprising braking the second hydraulic unit (172) when the wind speed (300) or the related parameter (n, P, p) has crossed the second threshold value (311) inversely to the first direction.

5

13. A control device (190) for a wind energy converter having a variable-ratio gear system (906, 802) mechanically coupled between a rotor (102) and a generator (104), the variable-ratio gear system (906, 802) including a first
10 transmission unit (172) coupled to a first shaft (165) and a second transmission unit (174) coupled to a second shaft (168), the control device (190) comprising:

a first control unit (192), which is arranged to adjust the
15 variable-ratio gear system (906, 802) to a first gear ratio at which the first shaft (168) substantially does not rotate;

a wind speed determiner (902), which is arranged to
20 determine a wind speed (300) or a related parameter (n, P, p);

a threshold detector (904), which is arranged to detect whether the wind speed (300) or the related parameter (n,
25 P, p) has crossed a first threshold value (310) in a first direction; and

a second control unit (194), which is arranged to adjust the variable-ratio gear system (906, 802) to a second gear

- 30 -

ratio at which the second shaft (165) substantially does not rotate, when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (311) in the second direction.

5

14. A wind energy converter comprising:

a rotor (102);

10 a generator (104);

a variable-ratio gear system (906, 802) mechanically coupled between the rotor (102) and the generator (104), the variable-ratio gear system (906, 802) including a first
15 transmission unit (174) coupled to a first shaft (168) and a second transmission unit (172) coupled to a second shaft (165); and

the control device (190) according to claim 13.

20

15. The wind energy converter of claim 14, wherein the generator (104) is a constant-speed generator, the variable-ratio gear system (906, 802) being configured such that at least one of the first gear ratio and the second
25 gear ratio corresponds to one of a minimum operational speed and a nominal maximum speed of the rotor (102).

16. The wind energy converter of claim 14 or 15, further comprising a clutch (400) for uncoupling the first shaft

- 31 -

(168) from the first transmission unit (174), when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

5 17. The wind energy converter of claim 16, wherein the clutch (400) is a double clutch comprising a first clutch position configured to couple the first shaft (168) to the first transmission unit (174), and a second clutch position configured to brake the first transmission unit (174).

10

18. The wind energy converter of claim 16, further comprising a brake (404) for braking the first transmission unit (174) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value
15 (310) in the first direction.

19. The wind energy converter of claim 18, further comprising a safety brake activator, which is arranged to activate the brake (402) in an event of the first or the
20 second transmission unit becoming inoperational along with activating a bypass (406).

20. The wind energy converter of one of claims 16 to 19, wherein the first and second transmission units (174, 172)
25 are first and second hydraulic units.

21. The wind energy converter of claim 20, further comprising:

- 32 -

at least one hydraulic conduit (176, 178) connecting the first (172) and second (174) hydraulic unit; and

5 a valve (408) for blocking the at least one hydraulic conduit (176, 178) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

22. The wind energy converter of claim 21, further
10 comprising a bypass (406) that interconnects the at least one hydraulic conduit (176, 178).

23. A method for improving the energy efficiency of a wind energy converter having a first and a second active module,
15 the method comprising:

obtaining a measurement of a wind condition;

determining, according to the obtained measurement, whether
20 a pre-determined operational condition is satisfied; and

based on a result of the determination, adjusting a configuration of a selected one of the first and the second active modules to achieve a predetermined power
25 characteristic of the wind energy converter.

24. The method of claim 21, wherein determining whether the predetermined operational condition is satisfied includes

- 33 -

determining whether a first or a second operational condition is satisfied.

25. The method of claim 22, wherein determining whether the
5 first operational condition is satisfied includes determining whether a magnitude of the obtained measurement has crossed a first threshold value in a first direction.

10 26. The method of claim 25, wherein determining whether the second operational condition is satisfied includes determining whether the magnitude of the obtained measurement has crossed a second threshold value in a second direction opposite to the first direction.

15 27. A control system for use with a wind energy converter having a first and a second active module, the control system comprising:

20 a sensor system for obtaining a measurement of a wind condition; and

a controller coupled to the sensor system, the controller being configured for:

25 determining, according to the obtained measurement, whether a pre-determined operational condition is satisfied; and

based on a result of the determination, generating a signal for adjusting a configuration of a selected one of the first and the second active modules to achieve a

- 34 -

predetermined power characteristic of the wind energy converter.

AMENDED CLAIMS
received by the International Bureau on 05 July 2010 (05.07.2010)

1. A method for operating a wind energy converter having a variable-ratio gear system (906, 802) mechanically coupled
5 between a rotor (102) and a generator (104), the variable-ratio gear system (906, 802) including a first transmission unit (174) coupled to a first shaft (168) and a second transmission unit (172) coupled to a second shaft (165), the method comprising:
- 10 adjusting the variable-ratio gear system (906, 802) to a first gear ratio at which the first shaft (168) substantially does not rotate;
- 15 determining a wind speed (300) or a related parameter (n, P, p);
- detecting whether the wind speed (300) or the related parameter (n, P, p) has crossed a first threshold value
20 (310) in a first direction; and
- adjusting the variable-ratio gear system (906, 802), when the wind speed (300) has crossed the first threshold value (310) in the first direction, to a second gear ratio at
25 which the second shaft (165) substantially does not rotate.

2. The method of claim 1, wherein the first and second transmission units (174, 172) are a first and a second

hydraulic unit.

3. The method of claim 1 or 2, further comprising driving the generator (104) at a constant generator speed.

5

4. The method of claim 2, wherein at least one of the first gear ratio and the second gear ratio corresponds to one of a minimum operational speed and a nominal maximum speed of the rotor (102).

10

5. The method of claim 2, further comprising uncoupling the first shaft (168) from the first hydraulic unit (174), when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

15

6. The method of claim 5, further comprising braking the first hydraulic unit (174) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

20

7. The method of claim 6, wherein a swivel angle (174a) of the first hydraulic unit (174) is adjusted to substantially stop a hydraulic flow through the first hydraulic unit (174).

25

8. The method of one of claims 5 to 7, the first (174) and second (172) hydraulic unit being connected by at least one hydraulic conduit (176, 178), the method further comprising

blocking the at least one hydraulic conduit (176, 178) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

5

9. The method of one of claims 5 to 8, the at least one hydraulic conduit (176, 178) being interconnected by a bypass (406), the method further comprising regulating the bypass (406) when the wind speed (300) or the related
10 parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

10. The method of claim 2, further comprising:

15 detecting whether the wind speed (300) or the related parameter (n, P, p) has crossed a second threshold value (311) inversely to the first direction; and

adjusting the variable-ratio gear system (906, 802), when
20 the wind speed (300) or the related parameter (n, P, p) has crossed the second threshold value (311) inversely to the first direction, to the first gear ratio.

11. The method of claim 10, further comprising uncoupling
25 the second shaft (165) from the second hydraulic unit (172), when the wind speed (300) or the related parameter (n, P, p) has crossed the second threshold value (311) inversely to the first direction.

12. The method of claim 11, further comprising braking the second hydraulic unit (172) when the wind speed (300) or the related parameter (n, P, p) has crossed the second threshold value (311) inversely to the first direction.

5

13. A control device (190) for a wind energy converter having a variable-ratio gear system (906, 802) mechanically coupled between a rotor (102) and a generator (104), the variable-ratio gear system (906, 802) including a first
10 transmission unit (172) coupled to a first shaft (165) and a second transmission unit (174) coupled to a second shaft (168), the control device (190) comprising:

a first control unit (192), which is arranged to adjust the
15 variable-ratio gear system (906, 802) to a first gear ratio at which the first shaft (168) substantially does not rotate;

a wind speed determiner (902), which is arranged to
20 determine a wind speed (300) or a related parameter (n, P, p);

a threshold detector (904), which is arranged to detect
whether the wind speed (300) or the related parameter (n,
25 P, p) has crossed a first threshold value (310) in a first direction; and

a second control unit (194), which is arranged to adjust the variable-ratio gear system (906, 802) to a second gear

ratio at which the second shaft (165) substantially does not rotate, when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (311) in the second direction.

5

14. A wind energy converter comprising:

a rotor (102);

10

a generator (104);

a variable-ratio gear system (906, 802) mechanically coupled between the rotor (102) and the generator (104), the variable-ratio gear system (906, 802) including a first
15 transmission unit (174) coupled to a first shaft (168) and a second transmission unit (172) coupled to a second shaft (165); and

the control device (190) according to claim 13.

20

15. The wind energy converter of claim 14, wherein the generator (104) is a constant-speed generator, the variable-ratio gear system (906, 802) being configured such that at least one of the first gear ratio and the second
25 gear ratio corresponds to one of a minimum operational speed and a nominal maximum speed of the rotor (102).

16. The wind energy converter of claim 14 or 15, further comprising a clutch (400) for uncoupling the first shaft

(168) from the first transmission unit (174), when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

5 17. The wind energy converter of claim 16, wherein the clutch (400) is a double clutch comprising a first clutch position configured to couple the first shaft (168) to the first transmission unit (174), and a second clutch position configured to brake the first transmission unit (174).

10

18. The wind energy converter of claim 16, further comprising a brake (404) for braking the first transmission unit (174) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

15

19. The wind energy converter of claim 18, further comprising a safety brake activator, which is arranged to activate the brake (402) in an event of the first or the second transmission unit becoming inoperational along with activating a bypass (406).

20

20. The wind energy converter of one of claims 16 to 19, wherein the first and second transmission units (174, 172) are first and second hydraulic units.

25

21. The wind energy converter of claim 20, further comprising:

at least one hydraulic conduit (176, 178) connecting the first (172) and second (174) hydraulic unit; and

5 a valve (408) for blocking the at least one hydraulic conduit (176, 178) when the wind speed (300) or the related parameter (n, P, p) has crossed the first threshold value (310) in the first direction.

22. The wind energy converter of claim 21, further
10 comprising a bypass (406) that interconnects the at least one hydraulic conduit (176, 178).

23. A method for improving the energy efficiency of a wind energy converter having a first and a second active module,
15 the method comprising:

obtaining a measurement of a wind condition;

determining, according to the obtained measurement, whether
20 a pre-determined operational condition is satisfied; and

based on a result of the determination, adjusting a configuration of a selected one of the first and the second active modules to achieve a predetermined power
25 characteristic of the wind energy converter, including causing a rotational component of the selected one of the first and the second active modules to substantially not rotate.

24. The method of claim 21, wherein determining whether the predetermined operational condition is satisfied includes determining whether a first or a second operational condition is satisfied.

5

25. The method of claim 22, wherein determining whether the first operational condition is satisfied includes determining whether a magnitude of the obtained measurement has crossed a first threshold value in a first direction.

10

26. The method of claim 25, wherein determining whether the second operational condition is satisfied includes determining whether the magnitude of the obtained measurement has crossed a second threshold value in a second direction opposite to the first direction.

15

27. A control system for use with a wind energy converter having a first and a second active module, the control system comprising:

20

a sensor system for obtaining a measurement of a wind condition; and

a controller coupled to the sensor system, the controller being configured for:

25

determining, according to the obtained measurement, whether a pre-determined operational condition is satisfied; and

based on a result of the determination, generating a signal for adjusting a configuration of a selected one of the first and the second active modules to achieve a predetermined power characteristic of the wind energy converter, including causing a rotational component of the selected one of the first and the second active modules to substantially not rotate.

STATEMENT UNDER ARTICLE 19 (1)

We herewith file amended independent claims 23 and 27 according to Article 19 PCT.

Arguments

The Examiner has identified a single reference, Hicks (WO 2008/149109), as relevant to the patentability of claims 23-27. If appropriate, please include the following arguments along with the amendments listed below.

Hicks appears to describe a variable ratio transmission including a hydraulic bypass circuit. The direction and magnitude of the power transmitted through the hydraulic bypass are variable and depend on the rotational speed of the rotor.

We submit that Hicks does not disclose or suggest a method including, among other features, “based on a result of the determining, adjusting a configuration of a selected one of the first and the second active modules to achieve a predetermined power characteristic of the wind

energy converter, including causing a rotational component of the selected one of the first and the second active modules to substantially not rotate,” as recited in amended independent claim 23.

Hicks may describe various configurations of the hydraulic units. For instance, in one mode of operation, hydraulic unit 180 is set to a near maximum stroke but rotates slowly, while hydraulic unit 500 is set to a near minimum stroke and rotates quickly (p. 8, lines 20-24). In a second mode of operation, “the stroke of unit 180 remains at or near maximum and the stroke of unit 500, initially at a minimum, is increased ... as a function of input speed” (p. 9, lines 19-21). In a third mode, “the stroke of unit 500 remains maximised but the stroke of unit 180 is reversed,” and the rotation of the two units is reversed (p. 10, lines 14-16). Thus, Hicks’ hydraulic units at most may rotate at different speeds or in different directions. However, in no case does one of Hicks’ hydraulic units “substantially not rotate,” as required by amended claim 23.

For at least this reason, we submit that claim 23 is patentable over Hicks. Since claims 24-26 depend from claim 23, these claims are also patentable for at least the same reason claim 23 is patentable.

Likewise, Hicks does not describe a control system for use with a wind energy converter, the control system comprising, among other features, a controller that is configured for, “generating a signal for adjusting a configuration of a selected one of the first and the second active modules to achieve a predetermined power characteristic of the wind energy converter, including causing a rotational component of the selected one of the first and the second active modules to substantially not rotate,” as recited in amended independent claim 27. Thus, claim 27 is also patentable over Hicks.

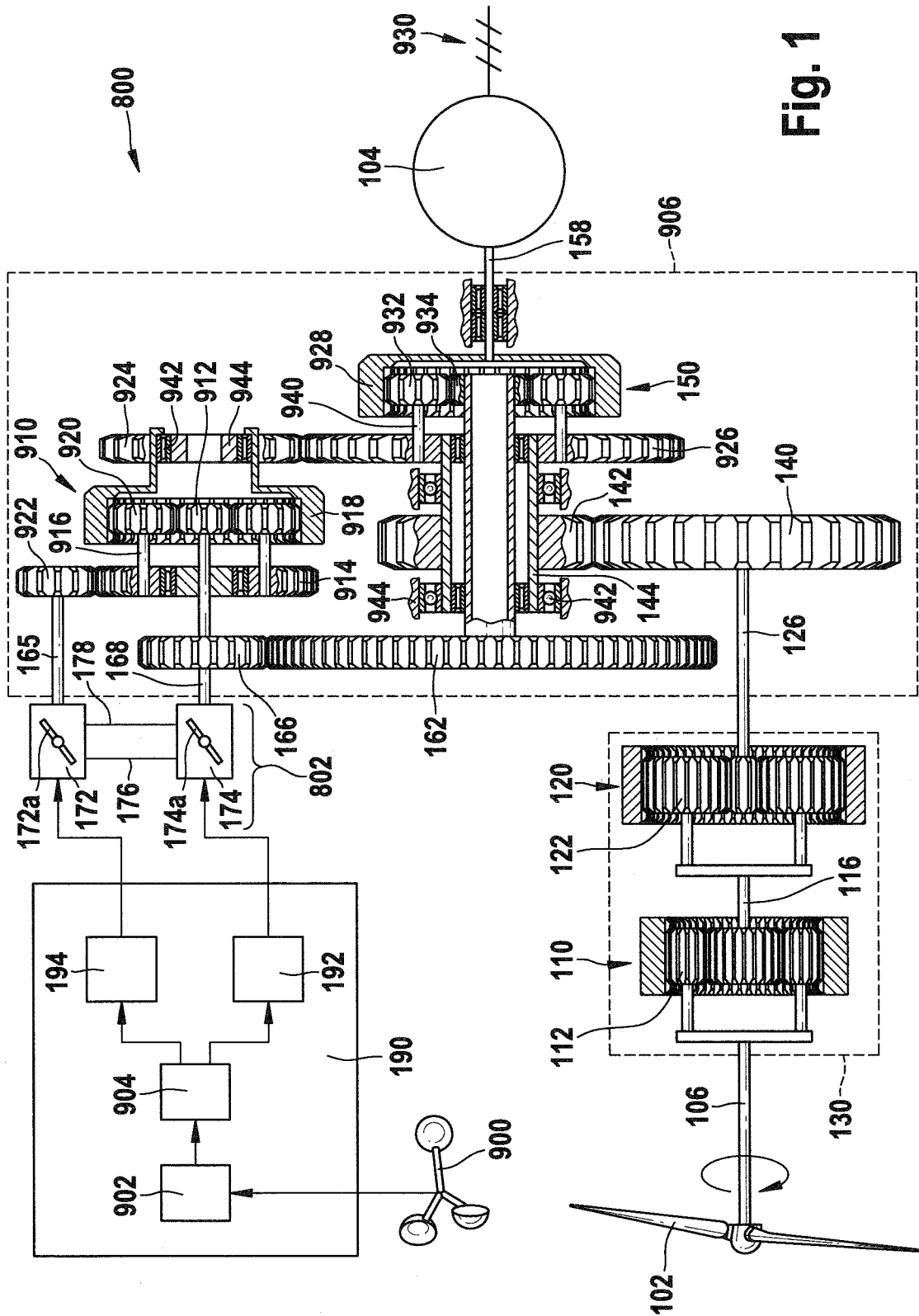


Fig. 1

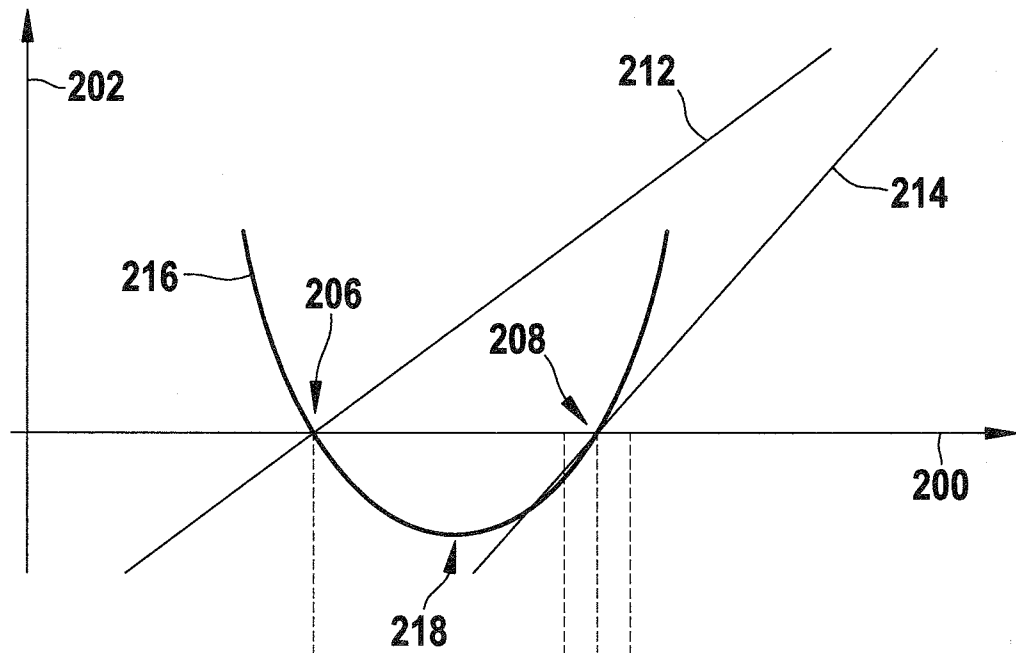


Fig. 2A

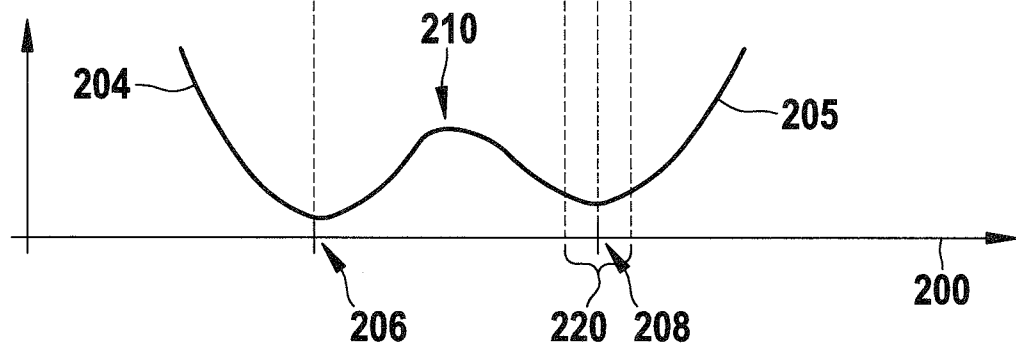


Fig. 2B

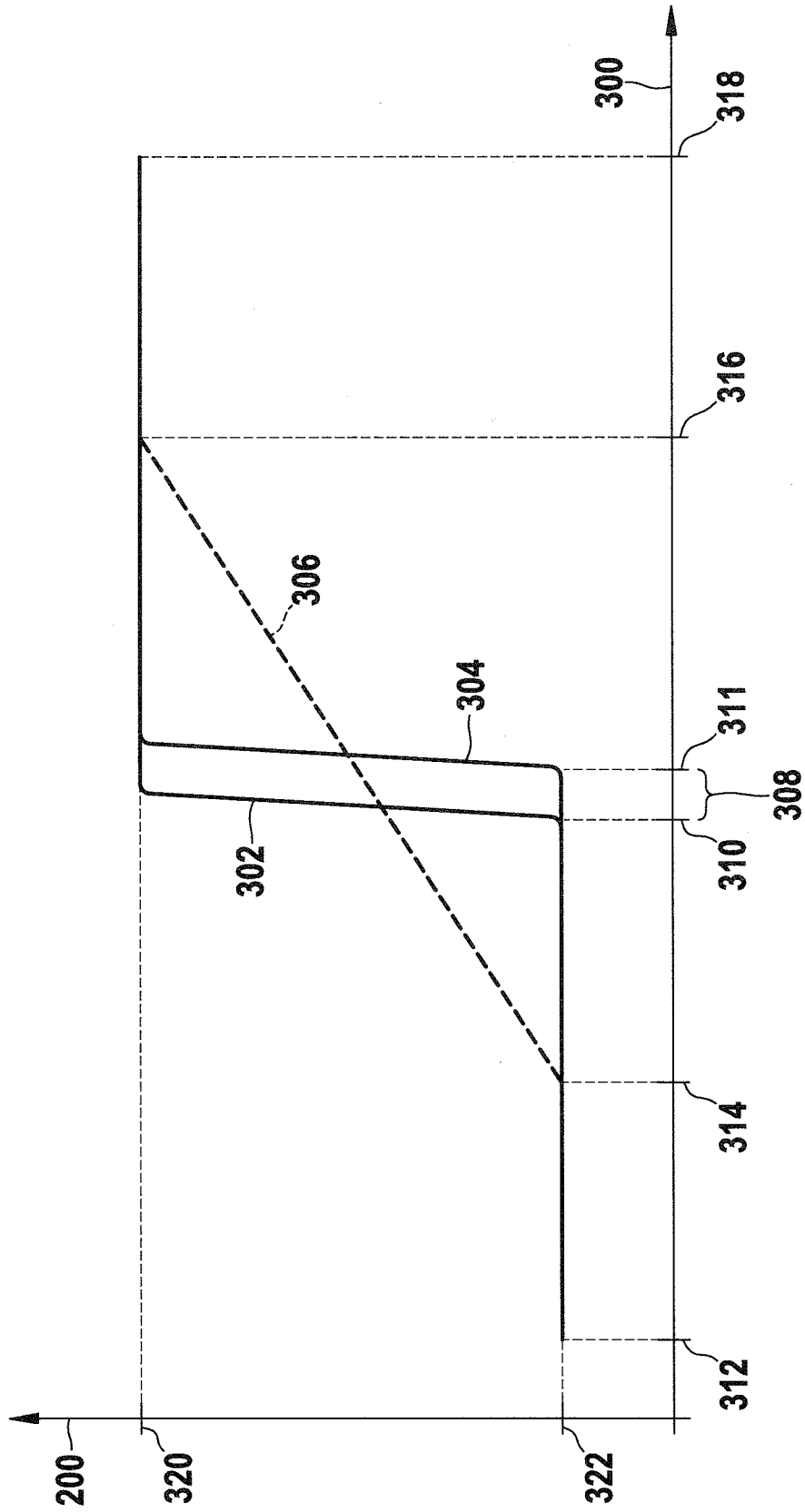


Fig. 3

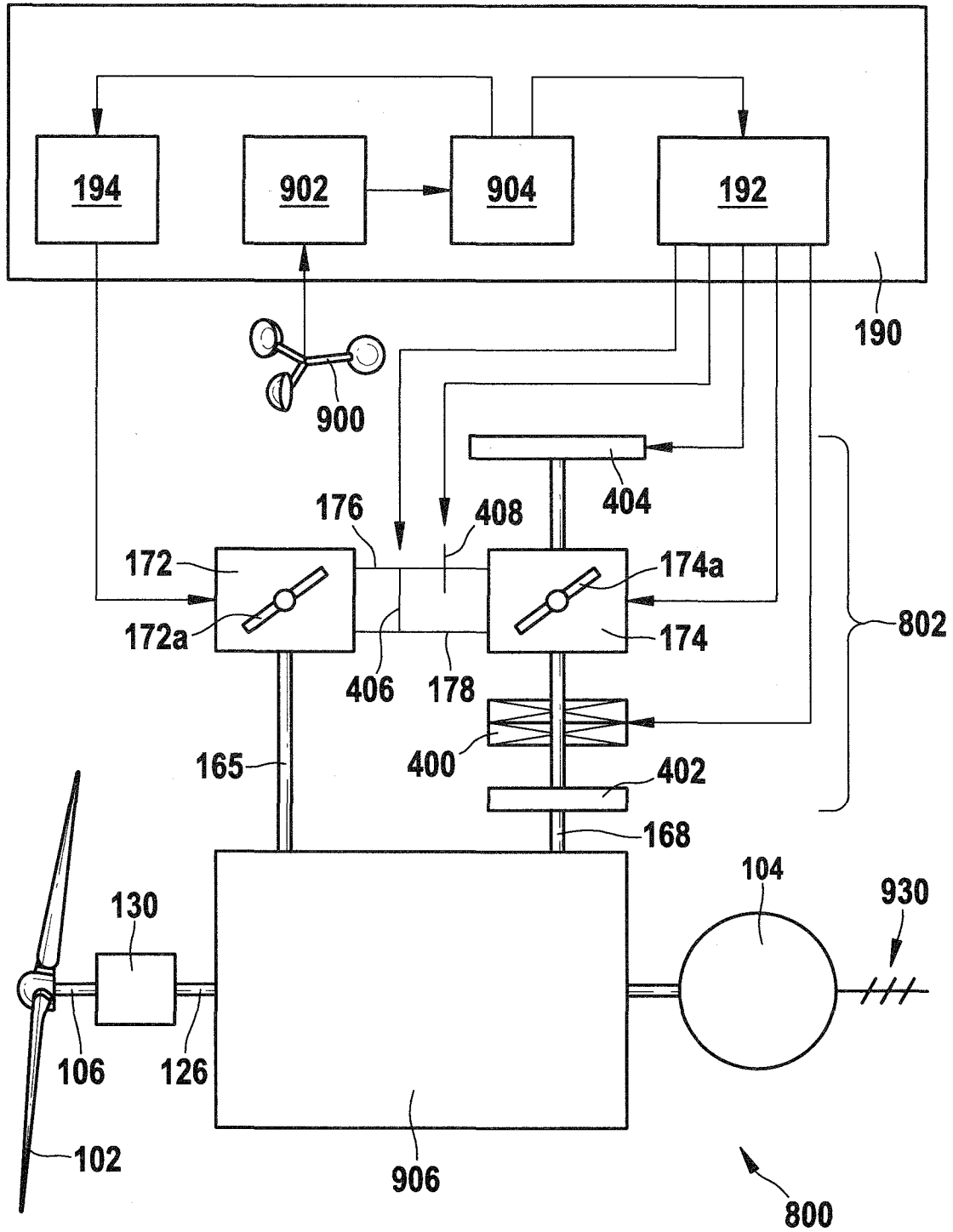


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2009/053302

A. CLASSIFICATION OF SUBJECT MATTER

INV. F03D11/02 F16H47/04 F03D9/00
 ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F03D F16H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/149109 A1 (ORBITAL 2 LTD [GB]; HICKS RAYMOND JOHN [GB]; CUNLIFFE FRANK [GB]) 11 December 2008 (2008-12-11)	23-27
A	page 7, line 11 - page 11, line 3; figures 1-8	1-22
A	WO 2008/061263 A2 (WINDTEC CONSULTING GMBH [AT]; HEHENBERGER GERALD [AT]) 29 May 2008 (2008-05-29)	1-27
A	page 3, line 18 - page 5, line 6; figure 1	
A	EP 1 895 158 A2 (NORDEX ENERGY GMBH [DE]) 5 March 2008 (2008-03-05)	1-27
	paragraphs [0007] - [0009], [0 21]; figures 3,4	

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

15 April 2010

Date of mailing of the international search report

04/05/2010

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040,
 Fax: (+31-70) 340-3016

Authorized officer

Jucker, Chava

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2009/053302

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008149109 A1	11-12-2008	CA 2689235 A1 EP 2162642 A1	11-12-2008 17-03-2010
WO 2008061263 A2	29-05-2008	AT 504395 A1 AU 2007324315 A1 CA 2670013 A1 CN 101583794 A EP 2100036 A2 KR 20090083468 A US 2010048350 A1	15-05-2008 29-05-2008 29-05-2008 18-11-2009 16-09-2009 03-08-2009 25-02-2010
EP 1895158 A2	05-03-2008	DE 102006040930 A1 US 2008054642 A1	20-03-2008 06-03-2008